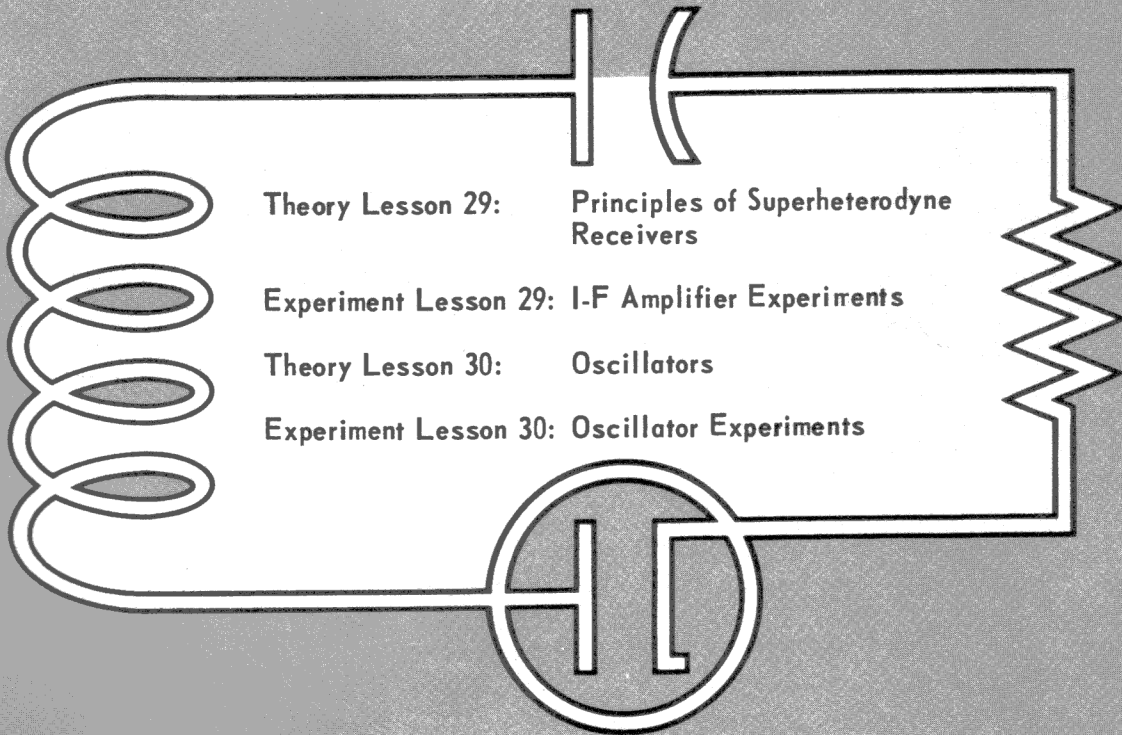


ELECTRONIC FUNDAMENTALS



Theory Lesson 29: Principles of Superheterodyne Receivers
Experiment Lesson 29: I-F Amplifier Experiments
Theory Lesson 30: Oscillators
Experiment Lesson 30: Oscillator Experiments

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA
New York, N. Y.



ELECTRONIC FUNDAMENTALS

THEORY LESSON 29

PRINCIPLES OF SUPERHETERODYNE RECEIVERS

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RCA INSTITUTES, INC.
A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL
350 West 4th Street, New York 14, N. Y.

Theory Lesson 29

INTRODUCTION

The biggest single shortcoming of the TRF receiver is the tendency of its bandwidth and gain to vary as the receiver is tuned over the 3:1 frequency range of the broadcast band. Although an r-f stage can be designed to have satisfactory gain and bandwidth for any one frequency the TRF receiver requires that all its resonant stages be tunable over a wide range.

In the days when TRF receivers were still popular, the average commercially made set suffered considerable variation of both gain and bandwidth. By modern standards, it had very low over-all gain. Elaborate shielding of the tubes, inductors, and even of the four or five sections of the variable capacitor was required in order to avoid feedback of the r-f signal between input and output r-f stages.

The TRF receiver was unsuited to short-wave reception. At the high frequencies of the short-wave band, feedback between input and output r-f stages would have been unpreventable in a practical receiver with enough gain to make short-wave signals usable.

The TRF receiver was not selective enough. As new stations came on the air, adjacent channel interference became a really aggravating problem to the broadcast listener. At the same time, his interest in long-distance reception was mounting. To hear a station in a city a thousand miles away was a much sought-after thrill.

The limitations of the TRF radio receivers were due to the fact that many stages had to be tuned. They could have been eliminated if all the stages were fixed-tuned.

29-1. THE SUPERHETERODYNE RECEIVER SYSTEM

The superheterodyne receiver avoids the major shortcomings of the TRF receiver by (a) converting the desired incoming carrier to a new frequency, called the *intermediate frequency* (i.f.) and (b) amplifying the intermediate frequency in fixed-tuned amplifiers that operate only at the intermediate frequency. The amplifier used to amplify the i.f., called an intermediate-frequency amplifier, contains several fixed-tuned circuits and one or more amplifying tubes. The i-f amplifier is designed to have high gain and a certain amount of selectivity. Since any incoming signal is converted to the intermediate frequency, the i-f amplifier will impart the same gain and selectivity to each signal. Thus, if you tune from station to station, the gain and selectivity should not change.

The great advantage of the superheterodyne receiver circuits lies in the ability of the receiver to always convert the incoming r-f signals to the intermediate frequency. How is this done? This action is performed by a section in the receiver called the *frequency converter*, or simply converter.

The location of the converter section in the superheterodyne receiver is shown in Fig. 29-1a. It precedes the fixed-tuned amplifiers because the desired signal must be selected and converted before reaching the fixed-tuned amplifiers. The converter section consists of the following portions:

1. A mixer tube and a variably tuned r-f input circuit that selects the desired carrier and admits the signal to the mixer.

2. An oscillator tube and a variably tuned oscillator tank circuit, to produce a local-oscillator signal that can be injected into the mixer.

By a complicated process that will be thoroughly discussed in a later lesson, the incoming signal and the local-oscillator signals mix together in the frequency-converter stage. At the output (plate load) of the converter section, there are the following signals:

- a. the incoming r-f signal
- b. the local-oscillator signal
- c. a signal whose frequency is equal to the difference between the incoming r-f frequency and the oscillator signal's frequency.
- d. a signal whose frequency is equal to the sum of the incoming r-f frequency and oscillator signal frequency.

- e. harmonics of the above signals.

Let us stress here that two signals are applied to the input of the converter:

- (1) the incoming r-f signal
- (2) the local-oscillator r-f signal

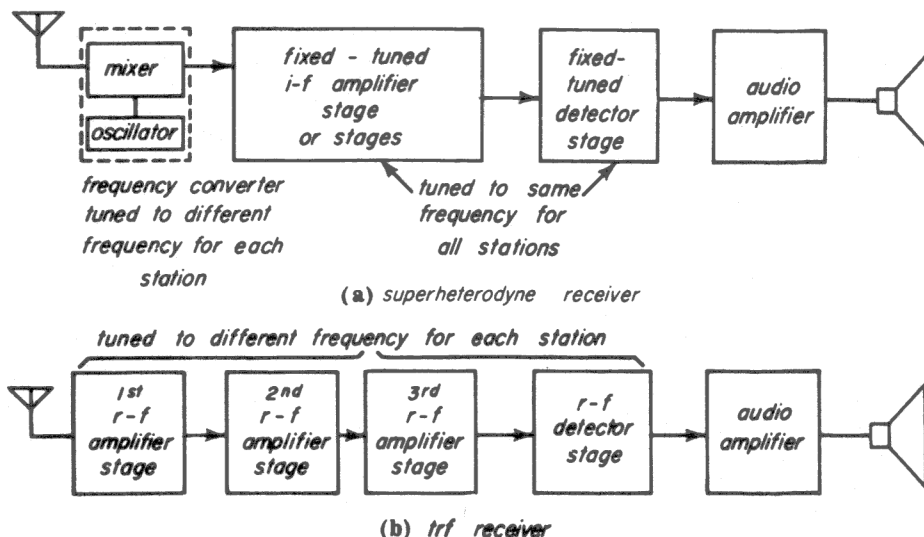
At the output, the *original* signals appear and the sum and difference frequencies of

the two original signals also appear. Also, many harmonic signals appear.

The plate load of the converter is a *fixed-tuned* load. It is usually tuned to the difference frequency, which we will call the intermediate frequency. The fixed-tuned load severely attenuates the other signals because they are far off-resonance. In the average superheterodyne, three other fixed-tuned circuits follow the fixed-tuned load. They also are tuned to the intermediate frequency.

The oscillator circuit is designed so that its frequency is away from the incoming r-f signal by an amount exactly equal to the i-f. If this were not so, the oscillator signal and the r-f signal would not produce the same i.f. for all incoming carriers, and the resulting i.f. would not go through the fixed-tuned i-f amplifiers.

The difference between the superheterodyne receiver and the trf receiver is illustrated in Fig. 29-1. Figure 29-1b is a block diagram of a TRF receiver. When a TRF receiver is tuned from one station to another, the resonant frequency of all its TRF stages is changed. On the other hand, the superheterodyne receiver that we have been discussing, shown in the block diagram of Fig. 29-1a, has fixed tuned stages. When the set is tuned from one station to another, only



how the superheterodyne differs from the t.r.f.

Fig. 29-1

the resonant frequency of the r-f input circuit and the resonant frequency of the oscillator tank circuit are changed. The four fixed-tuned circuits are not varied at all.

In these fixed-tuned i-f circuits the over-all bandpass and selectivity characteristics of the receiver are determined.

In most modern superheterodyne receivers, the converter section is designed to produce an i.f. of approximately 455 kc, and the fixed-tuned i-f transformers are designed to pass the i.f. *and its sidebands*. The i-f sidebands are created in the same way as the i.f. This may be easily demonstrated numerically.

When an r-f carrier at 1,000 kc is tuned in and admitted to the mixer, the oscillator frequency is automatically adjusted by the tuning mechanism to a frequency of 1,455 kc. The carrier emerges from the mixer at the difference frequency, 455 kc.

As you remember from your study of sidebands, a modulated r-f carrier is a carrier accompanied by sidebands. Let's consider a 1,000-kc carrier modulated by a steady 5-kc audio tone. Then, besides the r-f carrier, there will be an upper sideband of 1,005 kc and a lower sideband of 995-kc.

When the 1,005-kc sideband is heterodyned with the 1,455-kc oscillator signal, the difference frequency is 450 kc. When the 995-kc sideband is heterodyned with the 1,455 kc signal, the difference frequency is 460 kc.

Just as in the case of the modulated carrier wave, the output of the converter stage is a carrier and its sidebands. The converter output consists of the 455-kc i-f, the upper sideband of 460 kc, and the lower sideband of 450 kc.

The i-f signal with its sidebands is just like the r-f signal, except for its frequency. It is usually thought of as the r-f carrier converted to a lower frequency. This is why the mixer tube is called a converter. The process of deriving this i-f carrier is often called *conversion*.

Although the frequency of the carrier is changed by conversion, the *frequency difference* between carrier and sidebands is not changed. For a 5-kc audio tone, the sidebands are still 5 kc higher and 5 kc lower than the i-f. Thus the pitch of audio tones is preserved.

It is interesting to notice that when the upper sideband of the carrier is heterodyned with the oscillator frequency, it becomes the lower sideband of the i-f and the lower sideband of the r-f carrier becomes the upper sideband of the i-f.

It does not matter that the sidebands are criss-crossed in this way. They still accomplish their purpose just as well — they effectively vary the amplitude of the i-f carrier at a 5-kc rate.

We started this discussion of heterodyning by considering what happens when a carrier modulated with a steady frequency of 5 kc is beat against the oscillator signal.

In actual radio broadcasts, the r-f carrier is not modulated with a single frequency, but with the many frequencies that correspond to the pattern of the voices or music being broadcast. Therefore, the sidebands of the r-f carrier change in value from one instant to another in a pattern corresponding to the material being broadcast. The i-f sidebands change in the same pattern.

The audio content of the sidebands is separated from the i-f carrier in the diode detector, or second detector, as it is also called. In a later lesson you will learn that the mixer tube is a form of detector. It is called the first detector in the superheterodyne receiver because the signal passes through it before reaching the diode, which is now the second detector. The first detector does not separate the audio signal. It enables the tuned plate load to separate the i.f. from the other signals in its plate circuit.

29-2. TRACKING

In tuning a superheterodyne receiver, it would be a nuisance to have to tune the r-f

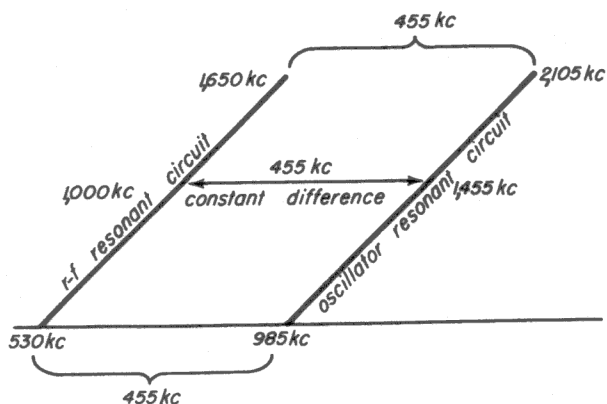


Fig. 29-2

input stage to the carrier and then have to separately tune the oscillator to the required heterodyning frequency in order to produce the i-f. Ganged tuning eliminates this difficulty.

Tracking Error. But ganged tuning in the superheterodyne is not as simple as in the trf. Suppose we want to tune one r-f input resonant circuit and one oscillator resonant circuit, or tank circuit. A two-gang variable capacitor is needed, since two circuits are to be tuned. But one circuit, the oscillator, must always be tuned to a frequency 455 kc higher than the other. That is, it must *track* with the other — keep a specific number of kc away just as one railroad track always keeps a specific number of inches away from the other (see Fig. 29-2).

If we use an ordinary two-gang capacitor with two identical sections, and an oscillator tank coil with less inductance than the r-f inductor has, the oscillator frequency will always be higher than the r.f. But will it always be higher by the same amount? The formula for resonance gives the answer.

Suppose the two sections of the variable capacitor have a minimum capacitance of 25 $\mu\mu\text{f}$ each, to which the trimmers add 15 $\mu\mu\text{f}$, making the minimum for each section 40 $\mu\mu\text{f}$. Using the formula:

$$f \text{ (in kc)} = \frac{159,200}{\sqrt{L \text{ (in } \mu\text{h})} \times C \text{ (in } \mu\mu\text{f})}$$

and rearranging the formula to give L, we have,

$$L = \frac{\left(\frac{159,200}{f}\right)^2}{C} = \frac{\left(\frac{159,200}{f}\right)^2}{40}$$

For the r-f inductor, whose highest resonant frequency, at minimum capacitance, is 1,650 kc, L is approximately 233 μh . For the oscillator inductor, whose frequency at minimum capacitance must be 455 kc higher, or 2,105 kc, L is approximately 143 μh .

In order that the r-f section of the variable capacitor may tune a 233- μh inductor to the low end of the broadcast band, at 530 kc, the maximum capacitance must be approximately 388 $\mu\mu\text{f}$. We find this value also from the formulas, which we rearranged as follows:

$$C = \frac{\left(\frac{159,200}{f}\right)^2}{L}$$

Since the two sections of the variable capacitor are similar, the oscillator section also has a maximum capacitance of 388 $\mu\mu\text{f}$.

Will this amount of capacitance tune an inductor of 143 μh to 985 kc (530 plus 455)? We apply the first formula to find out:

$$f = \frac{159,200}{\sqrt{143 \times 388}} = 676 \text{ kc}$$

Obviously the maximum capacitance is too much. It resonates with the inductor at 676 kc instead of 985 kc. The difference between the two frequencies, 309 kc is the amount of error, called the tracking error. It could be reduced considerably by removing some rotor plates from the oscillator section of the variable capacitor, and then closing the trimmer to compensate for the slight change in minimum capacitance caused by their removal. The minimum could thus be kept at 40 $\mu\mu\text{f}$. Now the maximum capacitance would be reduced. It might even be just right, and tune the oscillator to 985 kc. Thus the oscillator would have the correct frequency at the high and at the low end of the broadcast band. But it would not necessarily have the correct frequency at center. In fact, it would be almost 100 kc too high, as determined by calculations too lengthy to be given here.

Correction of Tracking Error. Even if the variable capacitor were of the straight-line-frequency type, tracking error would still occur.

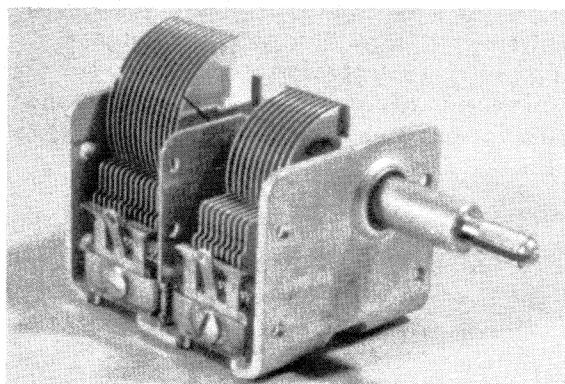


Fig. 29-3

But, if the manufacturer of the variable capacitor used the *slf*-shape or any other standard shape for the plates of the r-f section of the capacitor, and then modified the shape of the oscillator plates so that, at settings where the standard shape would insert either too much or too little capacitance to maintain tracking, the modified shape would insert just the right amount, the mistracking could be wholly eliminated. This is, in fact, the way in which the problem was solved (see Fig. 29-3).

This solution was completely satisfactory only if the receiver were designed for the broadcast band alone. The shape that was right for the broadcast band was all wrong for the short-wave band. Indeed, for the short-wave band, where the r-f and oscillator frequencies are very much higher than those of the broadcast band, the 455-kc difference between the two is a very small percentage of either. The same shape for both oscillator and r-f section is quite satisfactory, and the minute tracking error can be overcome by slight bending of the slotted end plates of the rotor sections.

For example, in the short-wave band from 6 to 18 mc, the frequency range to be covered by the r-f circuit extends from 6,000,000 cps to 18,000,000 cps. The range to be covered by the oscillator extends from 6,455,000 cps to 18,455,000 cps. The ranges are so nearly identical that both sections of the capacitor are required to be practically identical. Capacitors have similar numbers of plates and similar plate shapes for both r-f and oscillator sections.

Since the same variable capacitor is used in connection with different coils,

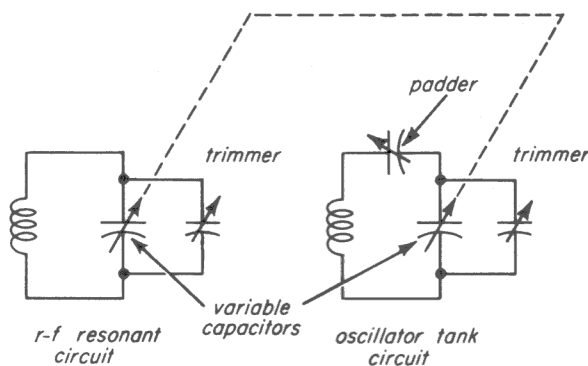


Fig. 29-4

when the receiver is switched to the broadcast band, some way must be available to adjust the capacitance range of the oscillator section to provide correct tracking for the broadcast band, even though the rotor sections are alike. The method used is capable of practically the same degree of accuracy of tracking that is achieved with the specially shaped plate. The tracking error that does occur can be kept so small that it is within the permissible limit for all parts of the tuning range.

The method consists simply of putting an additional capacitor, called a *padder*, in series with the oscillator section of the variable capacitor (see Fig. 29-4).

The principle on which the circuit works is that two capacitors in series have less total capacitance than either capacitor alone.

Thus, if a broadcast short-wave receiver uses a two-gang variable capacitor, with each section having a range from 40 to 390 $\mu\mu\text{f}$, the effective range of one section can be reduced by a series padder to an amount just suitable for the oscillator requirements. If a 400 $\mu\mu\text{f}$ fixed padder is connected in series with either section, the effective range of that section will become, approximately 36.5 to 198 $\mu\mu\text{f}$. If the padder is an adjustable capacitor which can be set, by turning a screw, to anywhere between 300 and 600 $\mu\mu\text{f}$, the effective range of capacitance in the oscillator circuit can be contracted or expanded by setting the padder. To contract the range, we need only to reduce the padder capacitance by opening the screw; to expand the range, we increase the padder capacitance by tightening the screw.

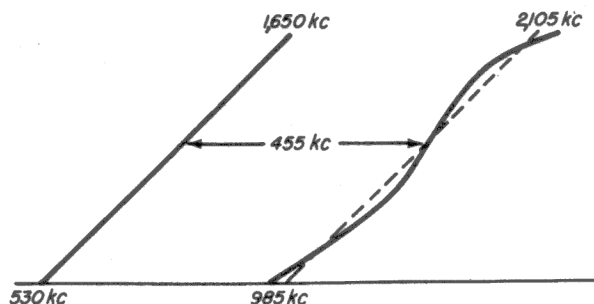


Fig. 29-5

When the oscillator inductor has the correct value in microhenries and the oscillator's *effective* capacitance range has been properly set by adjustment of the padder, satisfactory tracking will exist. As the variable capacitor is turned from the fully closed to the fully open position, the r-f resonant frequency will vary from 530 kc to 1,650 kc while the oscillator frequency will vary from 985 kc to 2,105 kc, with negligible error.

At all settings of the variable tuning capacitor, the oscillator frequency will be 455 kc higher than the r-f frequency, or *very nearly* so. At three settings, the difference will be exactly 455 kc; at other settings the difference will be slightly more or slightly less than 455 kc, as shown in Fig. 29-5.

The dashed line represents the ideal variation of oscillator frequency, always exactly 455 kc higher than the r.f. The solid S-shaped curve represents the close approximation possible with correct setting of the padder.

It might seem that, for those carrier frequencies where the corresponding part of the oscillator's S-curve departs from the ideal straight line, an i.f. would be generated which would have a frequency different from 455 kc. This is not the case. The receiver will be retuned until the oscillator is at a frequency which differs from the incoming carrier by 455 kc, even though the r-f resonant circuit is thereby slightly mistuned. If the oscillator is *not* correctly tuned, the output of the set sounds unnatural to the listener, who quite naturally adjusts the tuning control until normal sound quality is restored — that is, until the normal intermediate frequency is restored.

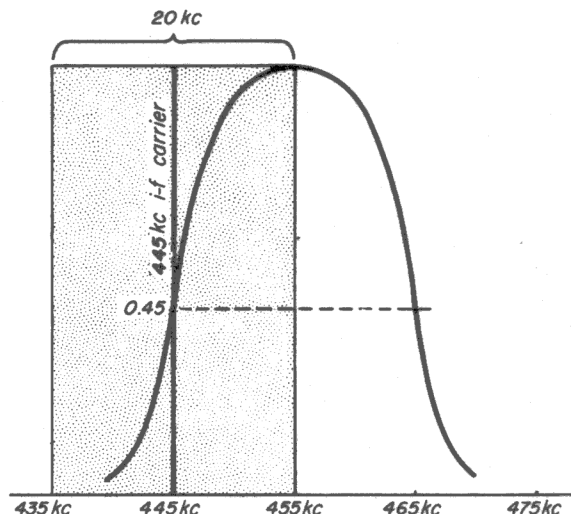


Fig. 29-6

An incorrect i-f produces distortion. When incorrect oscillator frequency produces an i-f signal which is several kilocycles off its correct frequency, the audio sidebands of the false i.f. fall on the wrong part of the i-f system's response curve. Some of the sidebands are amplified much more than others, as shown in Fig. 29-6, where the i-f carrier is at 445 kc. The receiver's i-f response curve is centered on 455 kc. Therefore, the carrier, at 445 kc falls well down on the lower slope of the curve, at a point where the relative gain is only 0.45. But the upper sidebands of the i-f signal, the sidebands due to 10-kc audio modulation, fall on the curve at 455 kc, where the relative gain is maximum. Those sidebands that fall near the maximum gain portion of the curve are amplified more than others. The audio frequencies corresponding to them are exaggerated in the output. Sidebands close to the i-f carrier, near the 0.45 relative gain level, are amplified less. The audio frequencies corresponding to them are reproduced at less than normal amplitude. The resulting frequency distortion makes the output of the receiver sound hissy.

When the oscillator frequency is corrected by retuning, the resonant frequency of the input circuit, which is not exactly 455 kc different because of slight mistracking, will not be at the same frequency as the incoming r-f signal, which *does* differ from the oscillator frequency by exactly 455 kc. The error of the input resonant circuit, if it

does not exceed 10 kc or so, will have little effect, because the bandwidth of the single resonant circuit is broad enough to let the r-f carrier and its sidebands pass without much loss, even though they are off resonance.

But in the i-f system, the i-f carrier must be accurately centered in the response curve, because the four fixed-tuned circuits of the average i-f system give it a bandwidth just wide enough to pass the sidebands satisfactorily. The bandwidth of the receiver as a whole is determined primarily by the i-f system.

29-3. IMAGE FREQUENCY

Ordinarily, the 455-kc i-f frequency originates when the desired r-f carrier is heterodyned with the local-oscillator signal. But it is possible for a 455 kc signal to originate when an *undesired* r-f signal is heterodyned with the local-oscillator signal. For instance a superheterodyne receiver might be tuned to a weak station transmitting on 600 kc. The local oscillator generates a signal at 1,055 kc, which is 455 kc higher than the r-f carrier. Thus there will be a difference of 455 kc, and this difference is sent on to the fixed-tuned stages after the converter. The stages after the converter receive the correct frequency but this frequency is very weak. If a strong station is transmitting on 1,510 kc, this frequency may also be passed by the input tuned circuit of the converter, because the input tuned circuit has a band-pass so broad that it may not fully attenuate the signal, 1,510 kc, even though it is tuned to 600 kc. Thus the 1,510-kc carrier may reach the grid of the mixer tube. It will be heterodyned by the local-oscillator signal. Since it differs from the frequency of the oscillator by 455 kc, an i-f signal of 455-kc will result. This undesired 455-kc signal will be accepted by the i-f amplifier, just as is the desired 455-kc signal that results from heterodyning the wanted signal with the oscillator signal. It will be detected and heard, just like the desired carrier. If the unwanted signal is much larger than the wanted signal as shown in Fig. 29-7 it may even be louder than the weak desired signal. Both audio programs will be heard

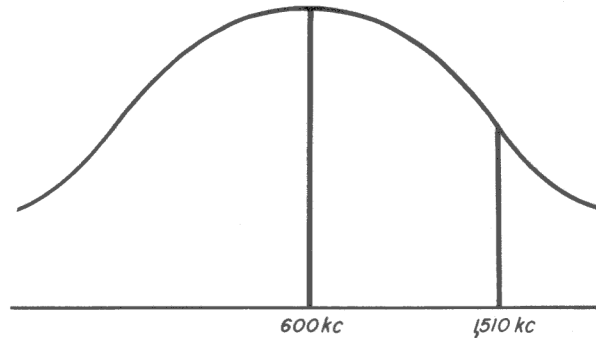


Fig. 29-7

at the same time, and the unwanted program may drown out the wanted one.

The frequency that produces the undesired i-f signal is called the *image frequency*, because some of its characteristics are like those of an image seen in a mirror.

The principle of the image frequency is shown in Fig. 29-8a and b. The image frequency is above the oscillator frequency, whereas the frequency of the desired signal is below it. (The image in a mirror appears to be on the far side of the mirror,

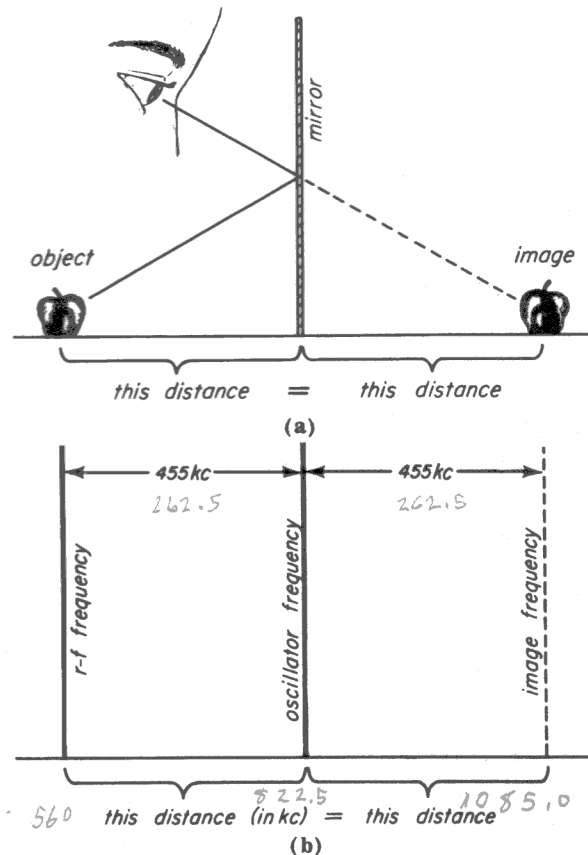


Fig. 29-8

whereas the object is on the near side. The image frequency is exactly as far away from the oscillator frequency, in kilocycles, as the desired signal is. The image seen in a mirror seems to be exactly as far from the mirror on the far side, as the object is on the near side.)

Image Frequency Affects Choice of I.F.

The image frequency is as far above the oscillator frequency, in kc, as the r-f frequency is below the oscillator frequency; therefore the distance between image and r.f. is twice the i-f frequency. For a receiver whose i.f. is 455 kc, the image is 2×455 , or 910 kc away from the r.f. frequency, as shown in Fig. 29-8b. Most receivers have an i.f. of 455 kc. Actually, 455 kc is a compromise based upon conflicting factors.

A high i-f frequency is desirable for attenuating the image frequency. The greater the difference in frequency between r.f. and image frequency, the more the image frequency is attenuated by the r-f resonant input circuit. Since the difference in frequency between the image frequency and the r-f carrier is twice the frequency of the intermediate frequency, making the intermediate frequency higher increases the difference between the r-f and image frequencies.

But there is a factor that opposes the use of a high i.f. Good selectivity among stations next to each other on the broadcast band requires that the i.f. be kept as low as possible. This selectivity is established almost wholly by the four tuned circuits of the conventional i-f system. The lower the intermediate frequency, the larger will be the *percentage* by which the interfering signal is off resonance in the i-f system. Therefore, the lower the i.f. the greater

the selectivity between adjacent channels. This is a difficult notion to grasp just from a statement of it alone. But it's really not as complicated as it looks.

Let's consider how this works out by using actual numbers. Consider two equally good i-f systems designed for different frequencies. Let one i-f system, system A, be tuned to 500 kc. System A gets its input from a mixer. This mixer receives an r-f carrier of 1,200 kc and beats it against an oscillator output of 1,700 kc. The resulting output, 500 kc, is the desired i-f frequency. The mixer also receives an r-f carrier of 1,210 kc, which is adjacent to the desired carrier of 1,200 kc. Because the tuning of the input-tuned circuit is broad enough to accept 1,210 kc, this carrier is also heterodyned with the oscillator frequency of 1,700 kc. Therefore, a frequency of 490 kc is sent to the i-f section. Thus, the undesired i.f. is 10 kc off the desired i.f. of 500 kc. This 10 kc is 2% of 500 kc.

Another i-f system, System B, has an i-f frequency of 100 kc. Once again, let's consider a desired signal at 1,200 kc and an adjacent undesired signal at 1,210 kc. Both the desired signal and the adjacent undesired signal will get through the broadly tuned r-f input circuits. Both signals will be heterodyned with the oscillator frequency, which, in this case, is 1,300 kc. The desired station will produce an i-f signal of the correct i.f. 100 kc. The undesired station will produce an i-f signal of 90 kc. This frequency is off resonance by 10 kc just as in the case of System A. But in System A, 10 kc represents only 2% of the resonant frequency; on the other hand, in System B, 10 kc represents 10% of the resonant frequency, as shown in Table A.

TABLE A

SYSTEM A – I.F. 500 KC			SYSTEM B – I.F. 100 KC	
Frequency	Desired Station	Undesired Station	Desired Station	Undesired Station
R-f carrier	1,200 kc	1,210 kc	1,200 kc	1,210 kc
Oscillator	1,700 kc	1,700 kc	1,300 kc	1,300 kc
Converter Output	500 kc	490 kc	100 kc	90 kc
Percentage Off Resonance	0%	2%	0%	10%

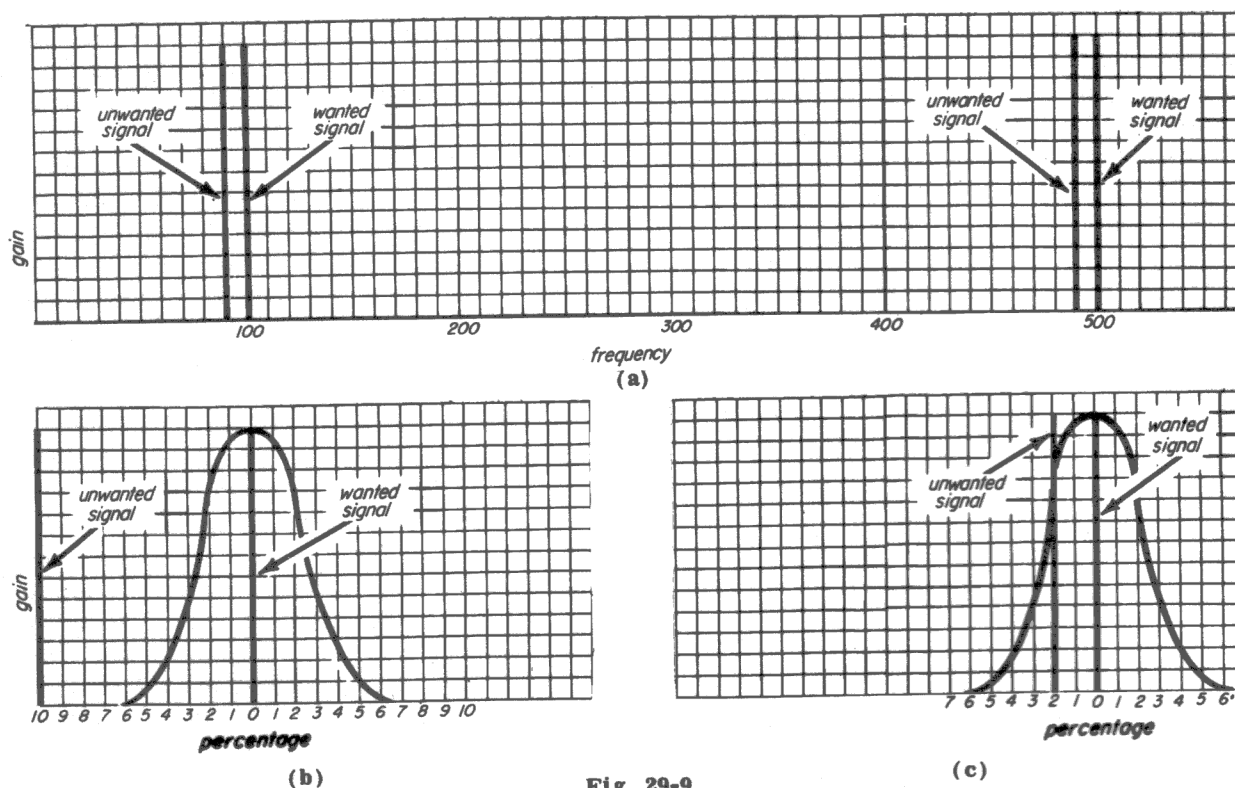


Fig. 29-9

System B will reject the unwanted i-f much more efficiently than will System A, as shown in Fig. 29-9. In *a*, the desired and undesired frequencies of both systems are shown. In *b*, and *c*, the percentages are expressed graphically. In *b*, the graph shows that when the unwanted frequency is 10 percent away from the wanted frequency, the bandpass, which does not extend much beyond the resonant frequency, is too narrow to pass the unwanted frequency.

In *c*, the graph shows that when the unwanted frequency is only two percent away from the wanted frequency, the bandpass, which is the same as in *b* of the figure, is wide enough to include the unwanted frequency.

Image frequency rejection requires a high i-f. but adjacent channel rejection requires a low i-f. A compromise was chosen by designers on the basis that image-frequency interference was more common and more troublesome than adjacent channel interference. Even at a high i-f. the two double-tuned i-f transformers severely attenuate a signal 10 kc off resonance. Most manufacturers have agreed on 455 kc, a high i-f. A small percentage of receivers use other intermediate frequencies.

29-4. CROSS-MODULATION

It is possible for an i-f. signal to originate without any assistance from the oscillator. Two r-f carriers, differing in frequency by 450 or 460 kc, can heterodyne each other in the mixer tube and produce an i-f. of 450 or 460 kc. Most i-f amplifiers have a wide enough bandpass to accept a signal that is so close to the resonant frequency.

This type of heterodyning differs in one interesting respect from that which occurs between the oscillator and an r-f carrier. In this type of heterodyning, both signals are modulated. Therefore, the single i-f signal resulting bears two modulation envelopes. It is said to be cross-modulated. Both audio programs are heard simultaneously.

Cross-modulating signals in the broadcast band cannot produce an i-f. of 455 kc, because no two broadcast stations are separated by 455 kc. No assigned broadcast frequencies end in -5, so no two can have a difference of 455 kc.

Cross-modulation of the i-f. stage can be prevented by placing tuned circuits ahead of the converter section of the receiver. These

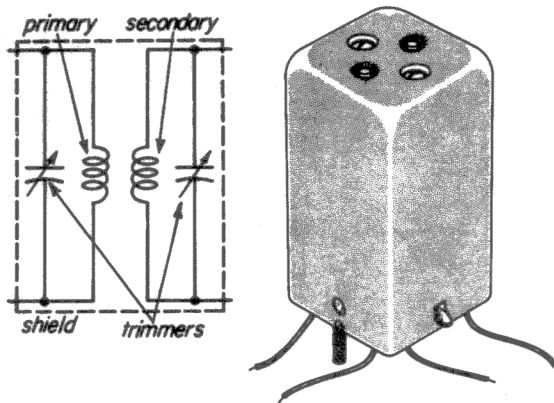


Fig. 29-10

tuned circuits can be made selective enough to eliminate one of two carriers that are as close together as 400 or 500 kc; thus, this eliminates the possibility of the two carriers cross-modulating and producing a frequency that the i.f. stages will accept.

29.5. DOUBLE-TUNED I-F TRANSFORMER

The double-tuned i-f transformer component is one of the characteristic features of the standard superheterodyne. It is shown schematically and pictorially in Fig. 29-10, as the coupling device that transfers the i-f signal from the converter or the mixer to the i-f amplifier tube, and from the i-f amplifier tube to the second detector. In the process of transfer, it also has a very marked effect upon bandwidth.

The dashed outline enclosing the schematic symbols of the windings and trimmers is usually omitted from conventional wiring diagrams, but it is understood to be there, even though not shown. It represents the metal container that shields the windings from magnetic fields around other inductors, and confines the fields it encloses. It prevents undesired coupling between the windings and other components in the receiver. This particular version shows adjustable trimmer capacitors used to tune the transformer to the desired intermediate frequency.

In other versions, small fixed capacitors are used. Tuning is accomplished by using powdered iron cores that can be screwed in to or out of the windings. One core, or slug, as it is commonly called, is adjusted through

a hole in the top of the shield can; the other is adjusted through an opening at the bottom, as illustrated in Fig. 29-11a. Some versions have brass screws imbedded in the slugs. The screws project outside the can, as shown at b. Cores not equipped with brass screws are themselves threaded and slotted, as shown at c. Some have screw-

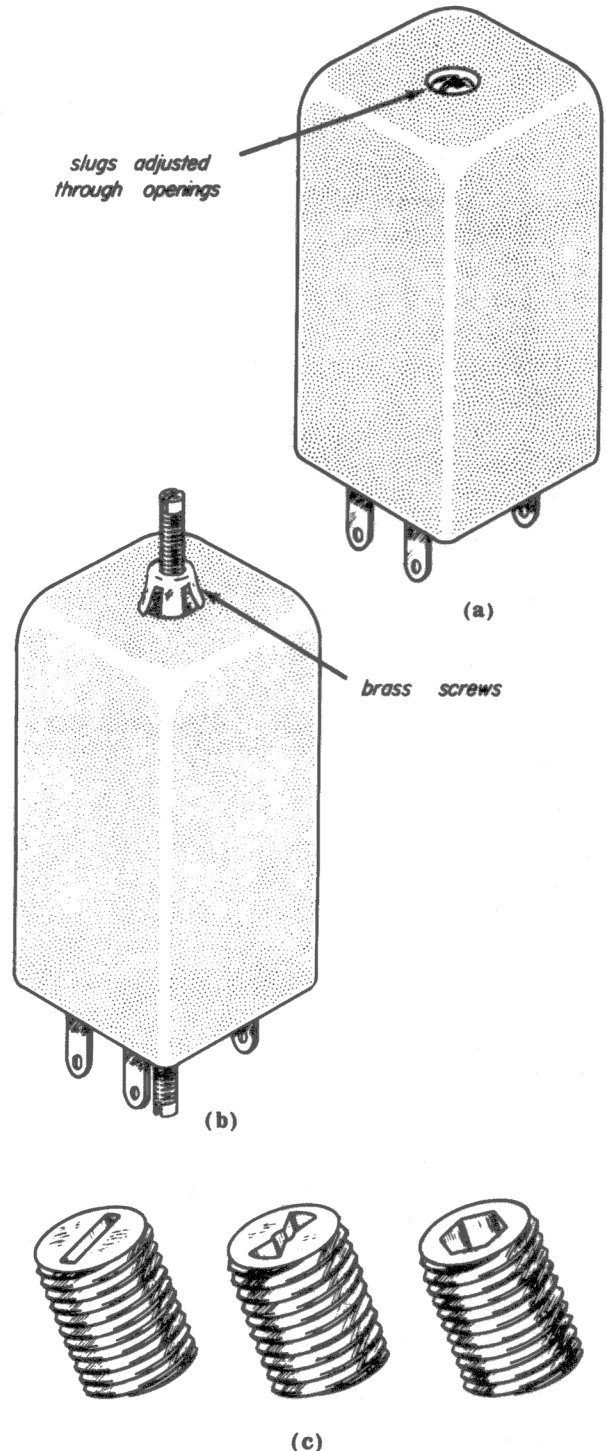


Fig. 29-11

driver slots, some have bow-tie slots, some have hexagonal holes running their entire length, making them adjustable from either end. Nonmetallic screwdrivers or aligning tools should be used to turn them.

Which slug (top or bottom) tunes the primary and which tunes the secondary cannot be determined by examining the shield can. Usually, it is necessary to consult the manufacturer's service notes for this information.

In the average superheterodyne, only two i-f transformers are used. The one located between the converter tube and the i-f amplifier tube is called the input i-f transformer. The one located between the i-f amplifier tube and the detector tube is called the output i-f transformer. If two stages of i-f amplification are used between the converter and detector, a third i-f transformer is required. It is located between the two i-f amplifier tubes. It is called an interstage i-f transformer.

In an effort to simplify the problem of stocking and replacing i-f transformers, some manufacturers have developed all-purpose, or universal, versions. These transformers embody a high degree of compromise between the different types. They may be used to replace input, interstage, or output i-f transformers, and will yield almost the same performance as the original more specialized part. Therefore one universal type can be stocked instead of three specialized types.

The dashed lines in Fig. 29-12a indicate magnetic coupling, due to physical nearness between the tuned primary and the tuned secondary of the transformer. When the primary and secondary are brought together, the coupling is increased – that is, primary and secondary share more magnetic lines, or have greater *mutual inductance*. When the two windings are close together, the transformer is said to be tightly coupled; when they are relatively far apart, the transformer is said to be loosely coupled.

When loosely coupled, and tuned to the same frequency, the two windings give the transformer an over-all resonance curve having the shape shown in the figure at b. The

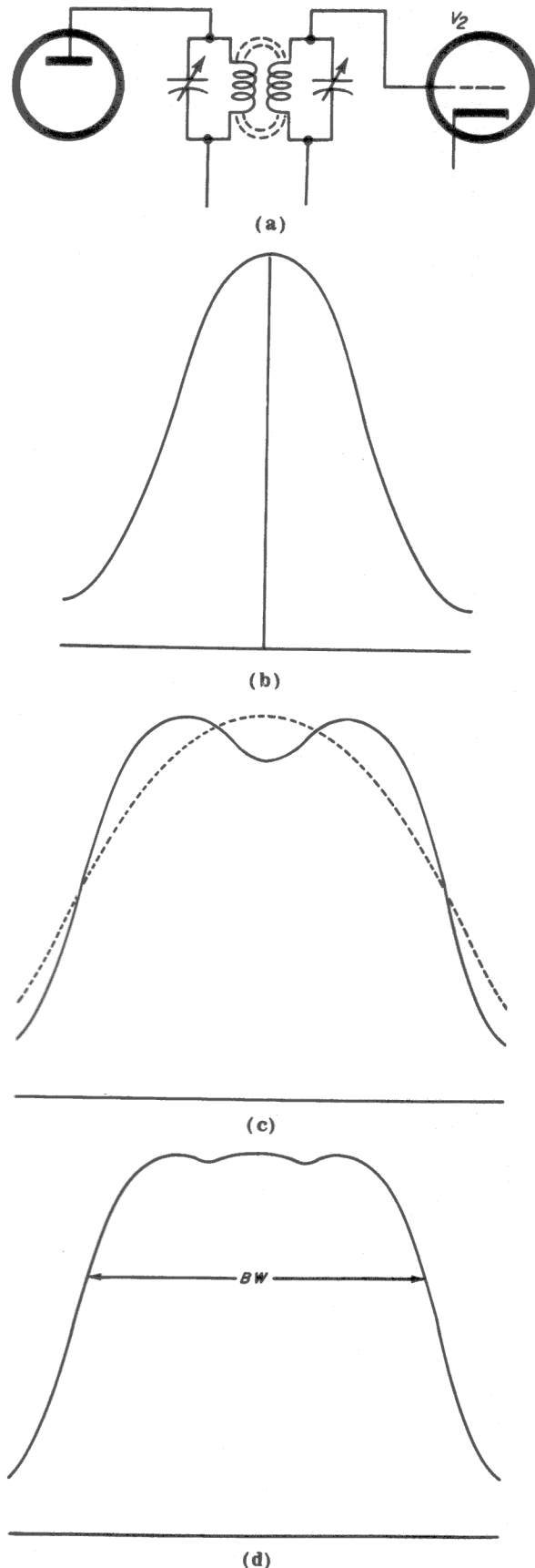


Fig. 29-12

curve is shown narrow, with steep sides, indicating that the bandpass is narrow, and that gain falls very rapidly for signals that are off resonance, becoming almost zero for signals more than 10 kilocycles off resonance. Selectivity is sharp.

If primary and secondary are moved gradually closer together, nothing happens at first, except a slight increase in gain. But as the coupling increases, a certain critical point is reached at which the single resonance curve shown at *b* begins to broaden into a new curve which, as the coupling increases more, develops two resonance peaks that move apart from each other. One moves in the direction of frequencies lower than the i-f; the other moves in the direction of frequencies higher than the i-f. Thus the bandwidth increases. At a certain degree of close coupling, the two resonance curves produce an over-all curve having the shape shown by the solid line at *c*. Note that the curve dips downward slightly at the middle — at the i-f. — indicating that gain at the i-f. is slightly less than it is at two places a few kilocycles off middle, where the peaks are. But also note that beyond these peaks, gain falls off rapidly, as indicated by the steep sides. A double-humped curve such as this has broader bandwidth than the single peaked curve, but beyond the band limits its selectivity is just about as sharp.

The loss of gain at and near the middle, or i-f, is objectionable. Sidebands containing the higher audio frequencies falling near the peaks, are amplified more than the sidebands containing the lower audio frequencies, which fall near the dip. Reproduction may sound hissy.

But if a stage of such double-peaked i-f amplification is followed by a stage of single-peaked, broadly tuned i-f amplification, as shown by the dashed line in *c*, the resonance curve of the i-f system (both stages considered together), will have the shape outlined at *d*. This has an almost flat top, indicating uniform gain for sidebands going nearly all the way to the band limits. Overall curves such as this are used in superheterodyne receivers intended for high-quality reception and reproduction of musical programs, where fidelity is the main consideration.

The tightest coupling at which the transformer still has a single peak, but would start to develop two peaks if coupling were increased, is called critical coupling.

In receivers used for communications, the i-f transformers are usually designed to provide narrow bandwidth, with consequent sharp selectivity. When signals come from far away and are therefore likely to be very weak, freedom from interference is of paramount importance.

29-6. VARIABLE BANDWIDTH I-F TRANSFORMERS

Sometimes a set owner may wish to hear a wide-range musical program transmitted by a local station. For this, a broad bandwidth in the i-f system is needed. At other times, he may want to hear a distant or weak station in a crowded part of the broadcast band, and a narrow bandwidth in the i-f system is needed. A compromise between these opposing requirements, such as the circuit in Fig. 29-13, is made in high-quality receivers, which have i-f transformers that

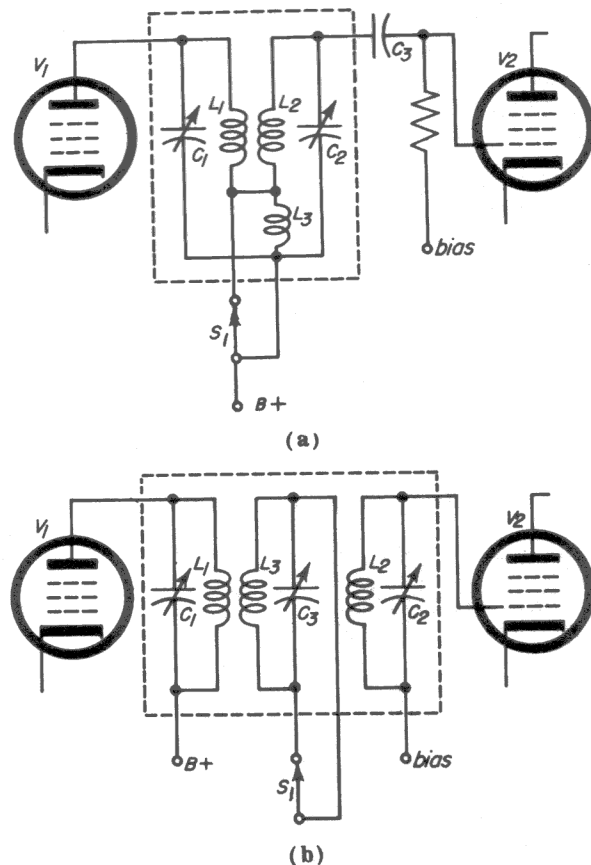


Fig. 29-13

can be given broad or narrow bandwidth as desired.

Figure 29-13a shows a convenient way of making the change. In addition to the usual primary and secondary, L_1 and L_2 , the transformer has a *tertiary* (third) coil of just a few turns, L_3 . The primary resonant circuit is L_1 , L_3 , and C_1 . The secondary resonant circuit is L_2 , L_3 and C_2 . Note that L_3 is part of both resonant circuits — it is a *mutual inductance*. It can be shorted out of the circuit by switch S_1 . When it is in the circuit, mutual inductance is increased. This is equivalent to bringing primary and secondary closer together. With increased mutual inductance, bandwidth is broadened. When the coil is shorted out, coupling is decreased, and bandwidth is narrowed.

Another method of achieving the same control of bandwidth is shown at *b* in the figure. Here the tertiary coil L_3 has as many turns as the primary and secondary. It is tuned by capacitor C_3 . It can be shorted out by switch S_1 . When S_1 is closed, a wire is connected across the terminals of L_3 and C_3 , thus preventing them from resonating. When it is tuned by C_3 to the same frequency as L_1C_1 and L_2C_2 , it acts as a mutual inductance, because it is magnetically coupled to both. L_1 and L_2 are then overcoupled. The bandwidth of the transformer is broad. When L_3 is shorted, a portion of the mutual inductance between L_1 and L_2 is destroyed. The bandwidth is narrow.

A third method has primary and secondary mounted on separate coil forms. A me-

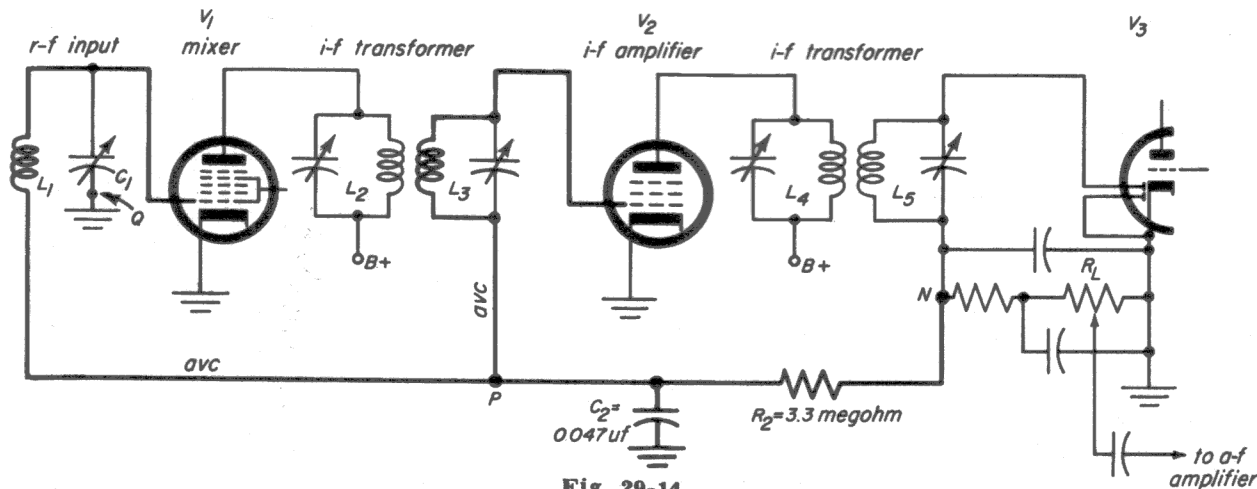
chanical arrangement enables the operator of the receiver to vary the distance between primary and secondary by rotating a control shaft. Since coupling varies, bandwidth varies. The method is seldom used.

29-7. AVC IN SUPERHETERODYNES

As shown in the schematic of Fig. 29-14, the diode detector (part of V_3) develops an audio voltage across the load resistor, and also a d-c voltage proportional to the amplitude of the incoming signal. The d-c voltage affords a source of control voltage that can be used to turn down the gain of the receiver when a strong station is coming in. One end of the diode-load resistor, across which the d-c voltage develops, is negative; the other end is positive. When the positive end is grounded, the other end will be negative with respect to ground. The stronger the incoming signal, the more negative will be the ungrounded end.

Let this ungrounded end, point N in Fig. 29-14, be connected through a suitable low-pass filter (R_2C_2) to point P. The negative voltage will be applied to point P. But because of the filter, which has a relatively slow time constant, the rapid audio variations across the diode load will not appear at point P. However, a negative d-c voltage will appear at point P.

As different stations are tuned in, negative voltages proportional to the strength of the carriers appear at P. But any negative voltage at P has a d-c path through L_1 and



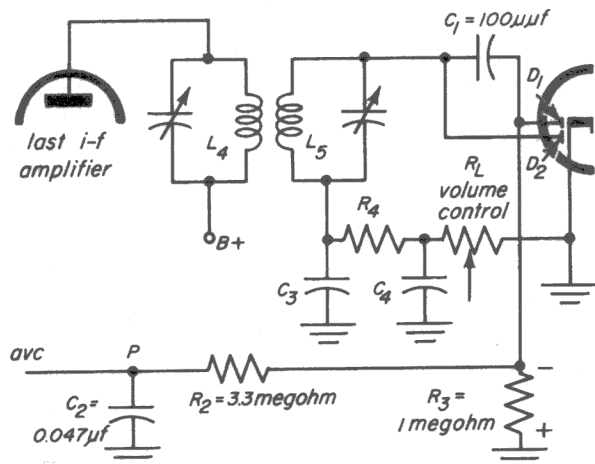


Fig. 29-15

and L_3 to the control grids of V_1 and V_2 . Thus, a strong carrier tends to develop a large negative bias on the grids, but a weak station develops only a slight negative bias on them.

Since the negative bias governs their plate current, V_1 and V_2 amplify less when the bias is large and plate current is low. That is, they amplify less when a strong signal is coming in. A strong signal, therefore, turns down the gain automatically as it comes in. If the volume control is not touched, but left at mid-position, while several stations are tuned in one after another, even though some of the carriers are weak and others strong, all stations are heard with approximately the same loudness, because the proportional bias reduces normal gain on strong carriers, and lets the gain remain up close to maximum on weak carriers. Thus, *automatic volume control* is achieved by the proportional bias alone. The operator of the receiver needs only to establish the desired volume level by mutual adjustment of the volume control. Thereafter, as he tunes from station to station, the automatic-volume-control circuit, abbreviated *avc*, adjusts the r-f and i-f gain to hold the output of the receiver at that level.

Note, in Fig. 29-14, that capacitor C_2 also serves to hold the low end of L_1 at r-f ground potential. L_1 and C_1 could not resonate if the r-f circuit were not complete. The low reactance of C_2 at radio frequencies is like a short connecting P to Q.

In some circuits, the deriving of *avc* voltage may be achieved by a slight modi-

fication of the circuit shown in Fig. 29-14. The modified circuit is shown in Fig. 29-15. In the duo-diode tube, one of the diodes is used for detection only, the other for developing *avc* voltage only. This separation of the *avc* function from the detector allows design changes in the *avc* circuit that do not affect the detector. In the practical modification, the i-f signal from the secondary of the last i-f amplifier is coupled to the *avc* diode, D_1 , through a small capacitor, C_1 , as shown. The signal thus applied to D_1 is rectified. The positive half cycles develop negative pulses across R_3 . The average value of these pulses is equivalent to a d-c voltage with the polarity shown. The filter, R_2C_2 keeps the pulses and the audio variations out of the *avc* bus. As in the other circuit, the d-c voltage is proportional to the strength of the incoming i-f signal.

Remote Cut-off Tubes for AVC. Amplifier stages controlled by *avc* voltage are expected to handle a wide range of signal strengths. Tubes suitable for such stages must amplify both strong and weak signals without introducing special troubles due to the characteristics of the tube. Pentodes having a remote cut-off characteristic are particularly suitable, because their high gain decreases in a smooth, gradual way as the *avc* bias increases. This desirable e_c - i_b transfer characteristic is due to the non-uniform spacing of the turns in the control grid. Figure 29-16 shows how this characteristic contrasts with that of sharp cut-off pentodes, which have uniform turns-spacing.

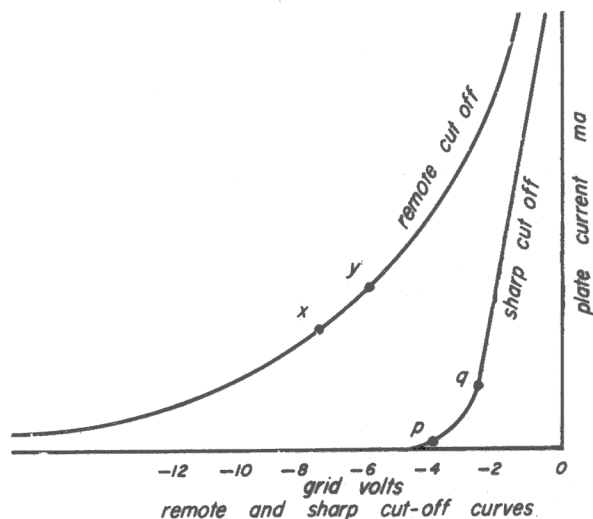


Fig. 29-16

The curve of the sharp cut-off tube is straight over most of its length. Near the bottom, it curves abruptly to the left, having a quite sharp bend. A relatively small negative bias reduces plate current to cut off. If a sharp cut-off tube is used as an r-f or i-f amplifier, and is biased to operate on the sharp bend between P and Q, it will partially detect the signal passing through it, modifying the signal's envelope. The altered envelope, when applied to the diode detector, will produce a form of distorted audio output called *modulation distortion*.

The sharp bend of the curve also resembles the sharp bend of a mixer tube's non-linear transfer curve (which you will learn about in a later lesson). Therefore, a cross-modulated signal may appear in the output of the sharp cut-off tube, just as it does in the mixer's output.

Modulation distortion, cross-modulation, and critical operation near cut-off are avoided when remote cut-off tubes are used. The remote cut-off transfer curve does not bend sharply enough to any place to cause effective detection or cross-modulation. For any ordinary signal, whose positive and negative swings might move the operating point within the range of X to Y on the curve, the used portion of the curve is linear. With such a curve the objectionable effects mentioned would be negligible, if produced at all. The following tubes are remote cut-off pentodes:

6SK7	7H7
6BA6	12BA6
6BJ6	12BD6
6K7	14A7
7B7	14H7

Fading and AVC Filter Time Constant.

When you are listening to a station whose signal strength varies — that is, a station which, due to distance, weather conditions, etc, fades up and down — AVC adjusts the receiver gain to compensate for the variations. As the signal diminishes, gain rises; as the signal increases, gain falls. The net result of the action is that the carrier signal applied to the detector has a nearly constant amplitude. If, however, the signal fades away to nothing, or practically nothing,

even maximum gain will not be enough to hold the input to the detector constant. Audio output of the receiver will fade, for AVC cannot compensate for extreme variations.

Within the range of signal-strength variations for which AVC is effective, the volume of the receiver will not vary greatly, even though the r-f signal does. But the *quality* of the audio output will change. As the signal becomes weak, and gain rises, the background noise, which is not fading, will rise in proportion to the gain. As the signal recovers, and gain falls, the noise will fall in proportion. Thus your ear notices the rise and fall of the background noise, even though the audio program remains steady. This action accounts for the peculiar swishing background of most short-wave reception.

Some stations fade in and out slowly, others rapidly. The time constant of the AVC filter must be short enough to follow rapid fluctuations of the signal. But it must also be long enough to keep the audio variations out of the AVC line. A compromise has to be made between the conflicting requirements. In communications receivers, the time constant is made short, even though this lets the very low audio variations feed back partially, thus partially cancelling themselves. In communications, steadiness of signal is more important than bass response.

In ordinary home receivers, the time constant is made longer — about one-sixth second.

Delayed AVC (DAVC). Even weak stations develop some AVC voltage. Any AVC voltage, however small, reduces the gain of the receiver below maximum. But weak stations require maximum gain. Therefore, it is helpful if the AVC action can be suspended while a weak station is coming in. By a simple modification, the AVC circuit can be held inoperative for signals that develop less than a certain voltage, such as 1-volt peak, at the diode plate. Thus, very weak stations will have the benefit of maximum gain. The AVC voltage does not start to reduce gain until a signal develop-



Fig. 29-17

A modification that introduces delay into the AVC circuit is shown in Fig. 29-17. A suitable resistor, R_k , is inserted between the diode's cathode and ground, making the cathode 1 volt positive with respect to ground, or making ground 1 volt negative with respect to cathode. Since diode D_1 is connected, through R_3 , to ground, D_1 is also 1 volt negative with respect to the cathode. But D_1 can conduct only when it is positive with respect to the cathode. The only time it can be positive with respect to the cathode is when a signal makes it more than 1-volt positive with respect to ground, so that it is more positive than the cathode. This happens when the positive half cycles of the incoming signal have a peak amplitude greater than 1 volt. Then D_1 conducts and develops AVC voltage. If the signals fails to exceed 1 volt, the diode does not develop AVC voltage.

The cathode resistor, R_k , is bypassed by capacitor C_k , to prevent degeneration when audio signals flow in R_k .

It was pointed out earlier in the lesson that a single resonant circuit selecting the r-f signals to be admitted to the converter tube has a broad bandwidth, and might admit strong image signals. If the stage of tuned r-f amplification precedes the converter input circuit, the chance of image signals getting through to the converter is greatly reduced. The likelihood of cross-modulation is also greatly reduced, because two carriers 450 kc apart could not readily pass through the much narrower over-all bandwidth of two tuned circuits in succession.

Besides narrowing the bandwidth of the input to the converter tube, the r-f stage increases the amplitude of weak signals before they reach the converter tube. This helps decidedly to improve signal-to-noise ratio on weak stations. As described in the preceding lesson, the signal is accepted and favored by resonance, while a large amount of the wide noise spectrum to which the tuned circuit is not resonant is excluded. This also reduces a hissing or rushing noise due to the converter tube, that is heard if the signal is not sufficiently amplified *before* passing through the converter stage. Thus the tuned r-f stage reduces both external and internal noise. Finally, it multiplies the over-all gain of the receiver greatly. Superheterodynes with a stage of r-f amplification quite commonly use a 3-gang variable capacitor. If permeability-tuned, they usually have three moving iron cores.

29-9. RESISTANCE-COUPLED R-F STAGE IN SUPERHETERODYNE RECEIVERS

Because the resistance-coupled r-f stage offered less gain than a tuned r-f stage, and did not contribute at all to selectivity, it was not suitable for use in the TRF receivers. They needed stages that provided optimum gain and selectivity. But in superheterodyne receivers, the resistance-coupled r-f amplifier stage has definite advantages.

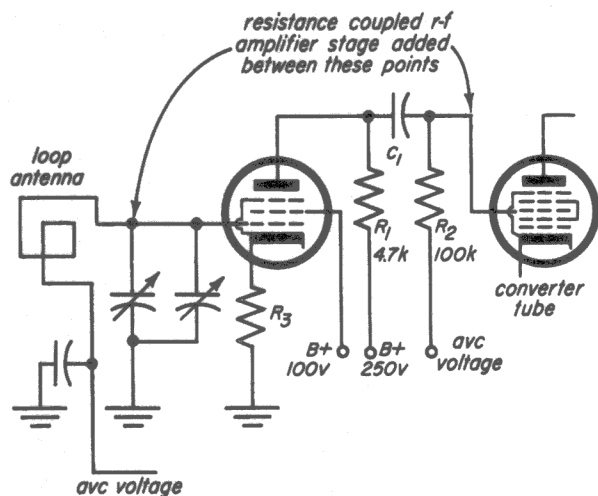


Fig. 29-18

It acts as a buffer stage, minimizing radiation from the receiver's antenna. Where the r-f input circuit is connected directly to the mixer grid, oscillator voltages induced on the grid may be radiated by the antenna, causing whistles (beat notes) in nearby receivers. The resistance-coupled r-f stage (Fig. 29-18) isolates the r-f resonant circuit from the mixer grid, thereby diminishing the amount of oscillator energy that reaches the antenna.

The resistance coupled r-f stage offers at least some gain. In a receiver as stable as the superheterodyne, more gain is always desirable. It is particularly desirable ahead of the converter tube. The incoming r-f signal can be amplified before it reaches the converter tube, resulting in a better ratio of signal to converter noise. And since a receiver's total gain is equal to the product (not the sum) of the gain of all its stages, the over-all gain of the receiver is multiplied by the number of times that the added stage increases the r-f signal. This may be as much as 15 times.

The resistance-coupled r-f amplifier stage does not require much space on the chassis. Since it is untuned, no extra section is required in the ganged tuning capacitor; no room is needed for a shielded coil. The only components needed are three small resistors, one small capacitor, one miniature socket, and one miniature high-gain tube.

Since the resistance-coupled r-f amplifier stage is untuned, it does not need to be

aligned, and therefore does not further complicate the alignment of the receiver as a whole.

Peaking-Coil Compensation. The response of such an r-f amplifier stage may fall off beyond the high end of the broadcast band because the bypassing effect of the stray capacitances and internal tube capacitances increases with an increase in frequency. The signal at the plate of the tube finds a low impedance path to ground through the capacitances, and is thereby attenuated.

The loss may be avoided, and the upper frequency range of the stage may be extended considerably, by inserting a small inductor (L_1) called a peaking coil in series with R_1 , the plate-load resistor (see Fig. 29-19a).

The value of the inductance is such that the stray capacitances, the tube capacitances and the distributed capacitance of the inductance itself, in combination, will

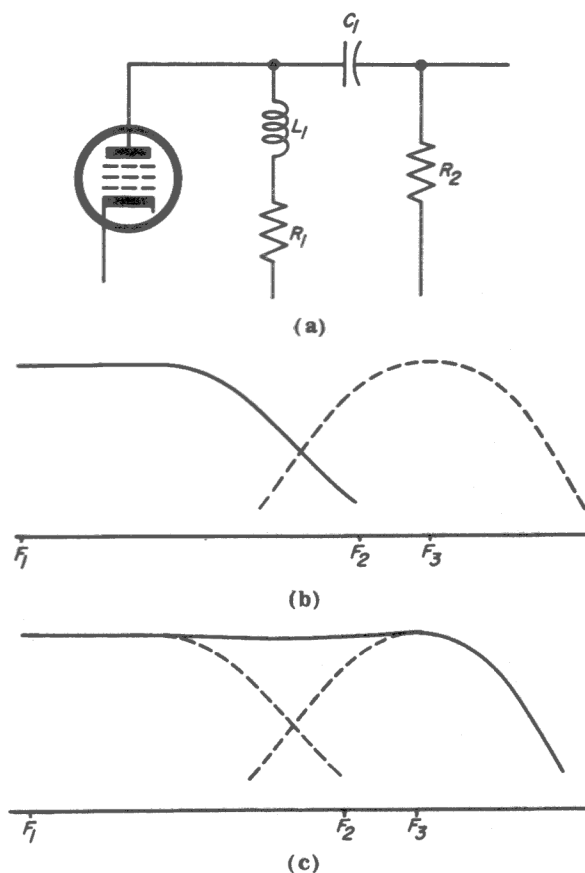


Fig. 29-19

resonate at a frequency slightly higher than the highest frequency to be amplified. Now the capacitances are helpful instead of being detrimental.

Let F_2 be the highest frequency to be amplified. With only the resistor, R_1 , in the plate circuit of the tube, the response curve of the stage would fall off as shown by the solid line in Fig. 29-19b. The gain would be quite low at F_2 . But with the peaking coil L_1 and the shunt interelectrode capacitance, the plate load would be resonant at F_3 . The response curve, if the peaking coil and capacitance were in the circuit, is shown by the dashed line in Fig. 29-19b. The over-all response curve is shown in Fig. 29-19c. Note that fairly uniform response is obtained up to F_3 . Gain at and near F_3 would rise.

29-10. A COMPLETE SUPERHETERODYNE CIRCUIT

Schematic Diagram. Figure 29-20 is the schematic of an efficient superheterodyne receiver. Eight waveforms are shown superimposed on the schematic diagram to emphasize the changes in the signal as it progresses from the r-f input of the receiver to the audio output.

The tiny amount of r-f energy (1) picked up by the loop antenna heterodynes with the oscillator signal (2) in the converter tube, V_1 . The resultant i.f. (3) is produced by the tube. I-F input transformer T_1 separates the audio-modulated i.f. from other frequencies in the plate circuit of the converter tube, and transfers it to V_2 , the i-f amplifier tube. The i-f signal emerges from V_2 with increased amplitude (4), and is transferred by output i-f transformer, T_2 , to the diode detector, which separates the audio information from the i-f carrier. The recovered audio signal (5) is developed across the diode load—the volume control, R_6 . A fraction of the audio signal is taken from the control by the wiper-arm tap and applied to the triode section of V_3 , a voltage amplifier.

The audio signal at the plate of V_3 is greatly increased in amplitude (6), and is

r-c coupled into the power-amplifier tube, V_4 . It appears in V_4 's plate circuit, with its voltage amplitude considerably increased (7) and its current amplitude greatly increased. The audio-output transformer, T_3 , a step-down transformer, reduces its voltage amplitude (8), however, it increases its current amplitude. The signal is now primarily a heavy current varying at audio frequency. This is the kind of signal required to develop enough power in the low-impedance winding of the voice coil to move the speaker cone.

The changes in amplitude shown are small compared to the actual changes, which would go off the page if drawn to scale. Note that the audio amplifier— V_3 and V_4 —is made available for reproducing the output of a phono pickup. A switch, S_2 , shown near the volume control, connects the amplifier input to either detector output or pickup output.

The first audio-amplifier tube, the triode part of V_3 , utilizes contact bias on its grid. It is a *high- μ* triode, having the grid winding quite close to the cathode. Thus the grid is in a part of the electron stream where the density of electrons is high. Some of the electrons strike the grid. If the electrons could not leak off, this would make the grid relatively negative with respect to the area that precedes it; namely, the cathode. In other words, the bias is developed within the tube and without a signal. The grid resistor determines how much of the total amount of electrons can leak off, and thus how much bias voltage is developed. Bias due to contact potential may be as high as -1.0 volt.

The dashed rectangle between V_3 and V_4 encloses symbols of eight small components used in the audio section of the receiver. All these components in a compact sub-assembly are shown pictorially below the rectangle. All eight components are created by printed circuitry on a single base of insulating material. The seven pig-tails required are numbered for identification. Thus printed circuit techniques make possible economy of parts.

Note, also, the hum-bucking primary winding of the power-output transformer. B+

